» Continental Europe Synchronous Area Separation on 08 January 2021

ICS Investigation Expert Panel » Final Report » 15 July 2021*

Executive Summary

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Disclaimer

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Executive Summary

On Friday, 8 January 2021 at 14:05 CET, the Continental Europe Synchronous Area was separated into two areas (the North-West area and the South-East area) due to cascaded trips of several transmission network elements. Immediately after the incident occurred, automatic as well as manual countermeasures were activated by European TSOs and the continental Europe power system was resynchronised at 15:08 CET. Overall no major loss of load or damages were observed in the power system.

In the immediate aftermath of the system separation, European TSOs in close collaboration through the ENTSO-E decided to start a joint process to collect all relevant facts regarding the incident. Based on these facts, the incident was classified as an incident of scale two ('extensive incident') according to the Incident Classification Scale (ICS) methodology, which was developed based on the legal obligations from the Commission Regulation (EU) 2017/1485 that establishes a guideline on electricity transmission system operation (SO GL). An incident of scale two requires the development of a detailed report by an expert panel composed of representatives from TSOs affected by the incident, a leader of the expert panel from a TSO not affected by the incident, relevant RSC(s), a representative of the subgroup ICS, the regulatory authorities and ACER upon request.

The respective ICS expert panel was established on 04 March 2021 and now presents its final report on the incident according to its mandate. The final report contains descriptions of the main aspects of the incident, which are subjected to an in-depth technical analysis regarding the causes of the incident and the explanation of these causes. Based on this analysis, recommendations are derived to mitigate the risk of future system separation events and their consequences. The final report is structured according to the sections briefly summarised below.

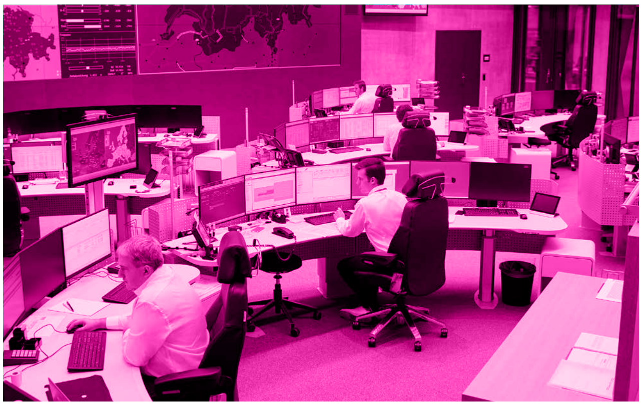
System conditions before the incident

The initial event that caused the system separation of 08 January 2021 took place in the Croatian substation Ernestinovo. The production by conventional power plants and renewable energy sources in the region of the system separation corresponded well to the scheduled production, and there was no unplanned unavailability of production units.

Extra-high voltage network lines were properly modelled in the network models used for congestion forecasts in the security calculations, i.e. day-ahead congestion forecast (DACF) and intraday congestion forecast (IDCF). The substation itself is equipped with two busbars, linked by a busbar coupler, which is protected by overcurrent protection. The trip of this busbar coupler, triggered by the overcurrent protection, was later identified as the initial event of the system separation.

The overall pan-European flow pattern on the afternoon of 08 January 2021 reflected a load situation with high exports from South-East Europe. This situation was caused, on the one hand, by warm weather in the Balkan Peninsula as well as the Orthodox Christmas holiday on 06 and 07 January, leading to an overall lower demand than usual in some of these countries. On the other hand, countries in Central and Western Europe saw colder weather and corresponding higher loads. This yielded a market-driven power flow from the south-east to the north-west of approx. 3,4 GW. The overall pan-European flow pattern was complemented by additional local flows. The local flow pattern was further determined in the range of 2 – 2,5 GW, so that overall a load flow of approx. 5,8 GW was obtained across the separation line.

In the hours prior to the incident, i.e. between 12:00 and 14:00, power flow on the busbar coupler was very high, causing several alarms to be triggered in HOPS (Croatian TSO) control centre. The situation was monitored and analysed by the dispatchers and assessed as stable. This assessment was mainly based on the obtained results from ongoing security simulations forecasting the further course of the current on the busbar coupler, yielding no further expectable overload. At 13:30, the flow on the busbar coupler was close to the forecasting results. However, in an excess of the forecasted flows in the day-ahead and intraday timeframe, after 14:00 a further increase of flow was observed on the busbar coupler. This caused an additional, now permanent, alarm. HOPS dispatchers and operators discussed potential remedial responses, but these could not be implemented since, shortly after the permanent alarm, the busbar coupler in Ernestinovo tripped due to the overload.



In the aftermath of the event, further analysis has been undertaken of the system security calculation, considering the interaction between the affected TSOs and the regional security coordinators (RSC) in the accounted time horizon of operational security calculations. TSOs deliver their individual grid models (IGM) to the responsible RSC, who merges the IGMs into a common grid model (CGM) of the whole synchronous area. In this regard, the complete topology of the substation Ernestinovo was not considered in the IGM by HOPS. HOPS modelled two busbars as one node, thereby neglecting the busbar coupler in the delivered IGM. While manual analysis of the correct topology was possible by HOPS, the missing information made it impossible to consider the realistic substation topology (including the busbar coupler) close to real-time and automatically in the operational security analysis. In general, this investigation stresses the high importance of an accurate operational security analysis across all timeframes with a proper modelling of the network and with particular reference to all the elements that may play a crucial role. The precision of the IGMs as well as of the observability area for real-time security calculation is an important contribution.

The regional coordination in the affected region was also analysed. The Balkan peninsula copes with the special situations of several EU- as well as non-EU-members, which produces differences regarding the coordinated capacity calculation (CCC) and the coordinated security assessment (CSA). Both aspects are integral to future regional coordination and will be addressed accordingly.

Derived recommendations

Based on the evaluations, which were summarised previously, several recommendations have been derived to eliminate the underlying causes of the incident.

Focusing on the general transmission system conditions prior to the incident, substation topology should have been chosen in such a way that the flow through the busbar coupler is as low as possible (recommendation R-1; details are set out in Chapter 1.1.3). Set points of protection devices which might trigger transmission equipment shall also be adapted to operational security limits and, if critical, be further exchanged between neighbouring TSOs (recommendation R-2; details are set out in Chapter 1.1.4).

In the light of the emerging situation, alarm settings must be defined in a clear way that is consistent with the protection devices, while operators' actions shall be predefined according to certain alarm levels (recommendation R-3; details are set out in Chapter 1.2.2.3). It will also be determined whether transmission reliability margins (TRM) and flow reliability margins (FRM) are sufficiently dimensioned to cope with sudden overloading (recommendation R-4; details are set out in Chapter 1.2.3.3).

For any operational security analysis, it should be mandatory to include outages of any transmission element in the contingency list, as well as details on whether elements have a cross-border effect and are protected by overcurrent and over-/under-voltage protection devices. The SCADA systems must allow for the calculation of the concerned contingencies (recommendation R-8; details are set out in Chapter 1.3.3.1). Data and model quality of the IGMs must furthermore allow the assessment of power flow limits of all concerned grid elements (recommendation R-9; details are set out in Chapter 1.3.3.1). In addition to this, the quality of the intraday congestion forecast should be assessed and improved to reduce the differences to real-time operations (recommendation R-10; details are set out in Chapter 1.3.4.2). Beyond this, the implementation of the common approach to determine and update the observability area should be monitored for the according real-time security calculations (recommendation R-6; details are set out in Chapter 1.3.2.2).

Regarding the regional coordination, the NTC calculation will be performed in a coordinated manner in each capacity calculation region (uncoordinated regional computation are still in place in some areas); the regional computation should also take into account existing stability limits (recommendation R-5; details are set out in Chapter 1.3.2.1). Finally, a sustainable solution should be found for coordinated capacity calculations (CCC) and coordinated security assessment (CSA) in the entire SEE (including Western Balkans) and/or between geographical regions if so relevant (recommendation R-7; details are set out in Chapter 1.3.2.2).

As several issues regarding the compliance with relevant codes, guidelines and methodologies could not be clarified in the timeline of the expert panel, it is agreed that a further detailed analysis of these issues is required (recommendation R-11; details are set out in Chapter 1.4).

Dynamic behaviour of the system during the incident

The busbar coupler in the substation Ernestinovo tripped due to overload protection at 14:04:25. This initial tripping of the busbar coupler led to the redirecting of the busbar coupler flow through the 400/110 kV transformers in Ernestinovo, which subsequently tripped shortly after because of overloading. Consequently, power flows were distributed to neighbouring transmission lines, causing a trip of the Serbian transmission line Novi Sad – Subotica as a result of overload protection.

The flow pattern from south-east to north-west as well as the tripping of the busbar coupler in Ernestinovo brought the power system to the verge of angular instability. The trip of the Serbian transmission line Novi Sad – Subotica instantly triggered this instability. Cascading disconnections of all transmission lines by distance protection from the border between Romania and Ukraine down to the Mediterranean Sea in the Dalmatian region ensued within 20 seconds.

As a consequence of the cascading disconnections, the system was separated into two synchronous areas: the south-east area yielded a surplus of generation and thus an increasing frequency, while the north-west area saw a surplus of load and thus a decreasing frequency. Before the system separation, the flow over the separation line totalled 5,800 MW.

After the system separation, the two areas, defined as the south-east area and the north-west area, had to handle the resulting power imbalance (–5,800 MW in the north-west area and +5,800 MW in the south-east area). In both areas the system protection schemes reacted rapidly and as expected, ensuring that the power system avoided any major damage and additional outages of lines.

The detailed analysis of the behaviour of the electrical system during the separation phase showed that the flows were very important between East and West; after the trip of the coupling and the Subotica – Novi Sad line, the two West-East areas started to separate from each other due to angular instability. This phenomenon could be reproduced by ex-post simulation and is consistent with the established facts.

Derived recommendations

Following the in-depth analysis of the dynamic phenomena, two recommendations are proposed in this chapter. The first is related to critical transmission system corridors: the stability margin has to be assessed in operational planning and real-time operations. Furthermore, operators have to be trained in the field of dynamic stability. TSOs shall rapidly develop proposals to transform the results of dynamic studies into concrete operational actions (recommendation R-12, R-12.1, R-12.2; details are set out in Chapter 2.3).

The second recommendation proposes that due to the future decrease of conventional power generation sources and a corresponding reduction of the system inertia, mitigation measures have to be identified (recommendation R-13; details are set out in Chapter 2.3).

Frequency support and analysis

After the system separation, the frequency in the south-east area increased with a rate of change of frequency (RoCoF) of 300 mHz/s and reached a maximum value of 50.6 Hz. The frequency in the north-west area decreased with a RoCoF of 60 mHz/s and reached a minimum value of 49.74 Hz. Due to the significant frequency deviations, all generation units that underwent primary control either decreased (south-east area) or increased (north-west area) their power generation accordingly. In addition, by exceeding the 200 mHz frequency limit, a high number of generation units changed their control mode and contributed according to the process of frequency stabilisation by either activating additional reserves in the north-west area or decreasing their generation further in the south-east area.

A further frequency decrease was arrested by the activation of the automatic frequency-dependent French system defence plan (approximately 1,300 MW) and the automatic frequency-dependent Italian system defence plan (approx. 400 MW). Both systems disconnected industrial loads as regulated by dedicated national contract agreements. Furthermore, through frequency support over HVDC links, the north-west area received a maximum of 535 MW of automatic supportive power from the Nordic Synchronous Area and 60 MW from Great Britain. In addition, an internal special protection scheme (SPS) in Turkey in the Marmara region activated which prevented a local blackout in Turkey by shedding 975 MW of power generation. The activation of the SPS in Marmara also helped to reduce the frequency rise and RoCoF in the South East area.

Several generation units (approximately 5.2 GW) and loads (296 MW) disconnected during the system separation. For a number of these facilities, this behaviour was conform with the national regulatory framework applicable to them: the capability to operate without disconnecting from the network within the range 49 Hz – 51 Hz (such range was never violated during the system separation) foreseen by Article 13 of Commission Regulation (EU) 2016/631 and Article 12 of Commission Regulation (EU) 2016/1388. These regulations are, in fact, compulsory only for new generation and demand facilities; for existing facilities, instead, different standard may be defined at national level.

For other facilities, instead, the disconnection showed a non-national grid code conform behaviour (either because they are new facilities subject to the Commission Regulation (EU) 2016/631 or to the Commission Regulation (EU) 2016/1388 or, because, even if existing units, they were nonetheless requested to comply with these or other equivalent standards according to the national regulatory framework).

Derived recommendations

Following post-event analysis of the frequency support and generation performance, five recommendations are proposed in Chapter 3. Where there was a non-conform disconnection of generation or loads, each TSO must review the cause with the owners of the power generating modules and distribution network operators to avoid non-conform disconnections in the future (recommendation R-14; details are set out in Chapter 3.2.2). Based on the recorded dynamic behaviour of the system, it is observed that the RoCoF values after the separation were within the generation withstand capabilities. The event will be used to evaluate frequency stability evaluation criteria for Continental Europe and to verify the dynamic stability models (recommendation R-15; details are set out in Chapter 3.2.2).

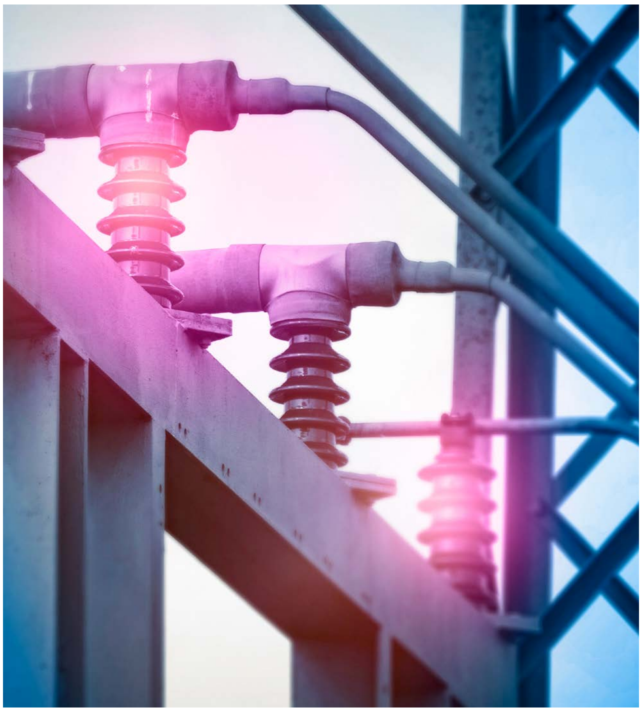
For higher power transfers between regions, the fast-acting power reserves may need to be complemented with additional fast support beyond the classical frequency containment reserves (FCR). Future scenarios should be evaluated to determine whether the available fast-acting support is sufficient in case a system separation occurs (recommendation R-16; details are set out in Chapter 3.3.2). The TSO system defence plans should also be assessed in this regard to determine any adverse cross-border impacts under different emergency state scenarios and to ensure that the defence plans (including special protection schemes) are coordinated and geographically balanced to meet the system needs (recommendation R-17; details are set out in Chapter 3.3.2). In addition, automatic frequency support from embedded HVDC systems should be assessed to further support the frequency management procedures where it is technically possible (recommendation R-18, details are set out in Chapter 3.3.2).

TSO coordination

During the incident, the TSOs that were impacted most by the event declared the corresponding system states in the ENTSO-E Awareness System (EAS). This allowed all TSOs in Europe to become aware of the seriousness of the ongoing incident. The system separation was confirmed in a call between 5 large TSOs in the north-west area. Furthermore, both the north and south coordination centres set alarms for frequency deviations according to the consequences in their coordination zones. EMS (Serbia) acted as frequency leader in the South-East area to coordinate the return of the system to 50 Hz whilst Amprion (Germany) acted in the same manner as the frequency leader in the north-west area due to its role as Synchronous Area Monitor (SAM).

The largest TSO in the South East area, Transelectrica, was theoretically required to act as frequency leader (as per Article 29 (3) of the Commission Regulation (EU) 2017/2196 on electricity emergency and restoration) in the south-east area, but they had to address the major disturbance in their grid and so could not assume the role; this meant that EMS, as a TSO with eight borders and the ability to communicate with almost all TSOs in the south-east area of the interconnection, fulfilled the role of frequency leader. The normal processes in relation to the role of the Synchronous Area Monitor and communication were important considerations in respect of choosing a frequency leader for the north-west area. The northern coordination centre (Amprion, which alongside SAM was responsible for frequency monitoring in January 2021) organised the communication and coordination of actions with the TSOs in the north and west of Europe and with the southern coordination centre (Swissgrid). Swissgrid was responsible for communication and coordination with the TSOs in the south of Europe and with Amprion. In the south-east area, EMS coordinated and communicated with Swissgrid and the most relevant TSOs in the south-east.

After stabilising both areas with automatic defence actions as well as manual countermeasures, the resynchronisation process started with HOPS (Croatia) acting as the resynchronisation leader. Moreover, resynchronisation actions were performed by the further affected TSOs, namely EMS, NOSBiH (Bosnia and Herzegovina) and Transelectrica (Romania). The actions that enabled the resynchronisation can be grouped into the following phases: preparatory actions and resynchronisation sequences. During the preparatory actions, EMS, HOPS, and NOSBiH agreed to form three strong reconnection points, which could then be used for the resynchronisation sequence. The resynchronisation sequences started with the reconnection of the busbar coupler in Ernestinovo, which was equipped with a synchro-check device



and was thus able to reconnect the two separated areas. Further reconnections were then performed on the other disconnected transmission lines in a coordinated manner. After approx. one hour (at 15:08), both areas were resynchronised and the normal operation of the synchronous area of Continental Europe was restored. After the resynchronisation process was completed, the power flow on the DC Link Monita between CGES (Montenegro) and Terna (Italy) was changed to the maximum of 600 MW in the direction of Montenegro to Italy to further reduce the flow through the busbar coupler in Ernestinovo.

The International Grid Control Cooperation (IGCC) platform used for the netting of imbalances between participating TSOs remained in service during the event. Theoretically, in case of a network split, a separation of the IGCC area could lead to a netting between two physically disconnected areas. On 08 January, the whole IGCC area was within the north-west area, except Croatia, which was partly separated due to the system separation. The IGCC did not affect the security of the network during the incident.

Overall, the communication during the system separation between TSOs was successful, which enabled a timely and efficient resynchronisation. The frequency was stabilised, and the two areas were fully resynchronised in approx. 1 hour after the first event. During this period there were several operational teleconferences and numerous more bilateral communications between TSOs to coordinate the required actions. The European Awareness System was also used to share information during the event.

Derived recommendations

Even though the communication, coordination and resynchronisation were successful and timely, this event can be used to identify further improvements in coordination and communication between TSOs for large-scale events.

Procedures for the management of balancing platforms during system events should be developed to avoid any unintended consequences which could lead to a larger disturbance of the system (recommendation R-19; details are set out in Chapter 4.1.6).

The European Awareness System was used successfully during the event and further functionalities should be developed to further assist TSOs in the sharing of operational data (pre and post fault) and coordinated actions (recommendation R-20; details are set out in Chapter 4.3.5). Furthermore, in addition to the currently established legal framework, a Region Continental Europe procedure for resynchronisation in case of system separation with two or more areas should be developed based on the experience of this event (recommendation R-21; details are set out in Chapter 4.3.5). Finally, in the future, coordination of regional restoration could be enhanced if it is deemed necessary by TSOs (recommendation R-22; details are set out in Chapter 4.3.5).

Market aspects before and after the incident

Data collected and analysed from the affected countries in the South-East European region (SEE) showed that the market was not impacted by the incident. The analysis indicates that all markets continued to operate as anticipated, both during and after the incident. The data trends highlight that at none of the borders of the affected countries did the market schedules exceed the NTC values. The results of the analysis shown in the report do not indicate any abnormal market behaviour in the day-ahead or intraday markets. The analysis also illustrates that there is no indication of any abnormal change in prices as well as fluctuations in the commercial schedules, such that the markets continued to function according to the agreed procedures at all times. In particular, the TSOs from the affected SEE countries (Serbia, Bosnia and Herzegovina, Romania, and Croatia) highlighted that no market activities were suspended at the time of the incident. For selected countries that were impacted by the incident through market-based extraordinary measures (ex. market-based load reduction), the impact of the incident on market platform performance was analysed. Intraday and balancing market data analysis from these areas did not show any special impact on traded volumes nor on market prices during or after the incident. The trading pattern during the particular hours merely varied around the daily average values rather than showing any peak values for volume or price.

Derived recommendations

No recommendations have been derived in regard to market aspects before and after the incident.

Overall assessment and conclusion

Overall, the incident was handled in a better and more efficient manner than the split in November 2006, which was also due to the lessons learned from that system separation and consequent development of the binding legal framework at the EU level. The ENTSO-E Awareness System (EAS), introduced right after the 2006 event, allowed the TSOs to be aware of the overall system states. Coordinated measures of the defence plans were activated quickly, which also allowed for the fast resynchronisation of the two asynchronous areas.

Analysis shows that in addition to the already established high flows due to the market positions, there were non-forecasted flows which contributed to the high flow through the busbar coupler in Ernestinovo. Due to these non-forecasted flows and incomplete modelling of the busbar coupler (with single node in IGM), the affected TSOs and RSCs were not able to perform an accurate analysis of N-1 security. This impeded the proper estimation of the network status, not allowing the affected TSOs to be aware of the risk and to prepare proper and timely remedial actions.

Moreover, it was shown by the in-depth analysis that the large pan-European load flow and the subsequent low stability margin was crucial for the incident, which reveals an illuminating view on future power system conditions in Europe. With the ongoing energy transition, large and long-ranging power flows on the pan-European level will further increase in amplitude and occurrence. In this regard, power system operation must be sufficiently resilient to cope with unexpected disturbances and faults to guarantee an unchanged high security of supply of European customers. Therefore, sufficient security margins must be provided if increasingly high utilisations of assets are necessary to cope with the electrical energy transition. Power system operation will be further challenged, emphasising the importance of according highly accurate security calculations. In all these regards, the ICS expert panel has provided numerous recommendations both for further assessments and corresponding implementations. The implementation of these recommendations will help to prevent similar incidents in the future.

Recommendations

Based on the evaluations, which were previously summarised, several recommendations have been derived to eliminate the underlying causes of the incident.

The Expert Panel invites ENTSO-E/TSOs and ACER/NRAs to coordinate on developing a prioritisation list, deliverables and recommendation deadlines with a view to publishing it by the end of 2021.

Recommendation concerning the substation topology

ID	Recommendation	Justification	Responsible
Substation Topology			
R-1	The **substation topology** should be chosen in such a way that the **flow through the busbar coupler is as low as possible**. This should also be reflected in any TSO guidelines within the company where rules for the substation's topology are described.	On the day of the incident the topology led to the flow through the busbar coupler being relatively high and covering the flow of two subsequent transmission lines. A change of the topology of the substation can optimise the flow on the busbar coupler and thus lead to a reduction of the flow. Consequently, a possible outage of the busbar coupler will have a limited impact.	TSOs

Recommendation concerning the setting and exchange of the protection parameters

ID	Recommendation	Justification	Responsible
Setting and exchange of the protection parameters			
R-2	Each TSO must transpose the set points of the protection equipment to **operational security limits**. To coordinate the protection of their transmission systems, neighbouring TSOs **shall exchange the protection set points** of the lines for which the contingencies are included as external contingencies in their contingency lists.	The sharing of the protection set points/operational security limits with regards to the observability area enables all impacted TSOs to realistically assess the system.	TSOs

Recommendation concerning Alarm levels

ID	Recommendation	Justification	Responsible
Alarm handling in control centre			
R-3	The **alarm levels** must be **clearly defined** and shall be consistent for all network elements. This also requires a harmonised protection device setting. It is recommended to define operators' actions at different alarm levels and appropriate remedial actions in order to resolve the problem.	The alarm levels must allow enough time for the operator to decide on and activate remedial actions. For each alarm level, clear predefined remedial actions tell the operator how to resolve the problem.	TSOs to implement, ENTSO-E to monitor

Recommendation concerning Reliability Margins

ID	Recommendation	Justification	Responsible
Capacity calculation			
R-4	It shall be **assessed** if the Transmission Reliability Margins (**TRM**) and the Flow Reliability Margins (**FRM**) are sufficient to cope with sudden high overloading.	Real-time variations in the power system are covered by TRM in NTC calculations and Flow Reliability Margins (FRM) in FB Market Coupling. A sudden increase of Area Control Errors was identified as one of the critical factors contributing to the event. With regards to the establishment of several European Balancing Platforms in the course of the next 12 months (IGCC, PICASSO, MARI) it shall be assessed whether the current approach for the determination of margins (TRM, FRM) is sufficient.	TSOs of the CCRs

Recommendation concerning coordinated capacity calculation

ID	Recommendation	Justification	Responsible
Capacity calculation			
R-5	The NTC calculation shall be performed in a coordinated manner in each Capacity Calculation Region. The **coordinated NTC calculation** has to consider existing **stability limits**.	A regional approach is a way to examine the situation holistically so as to overcome the shortcomings of coordination that occur with the application of only the bilateral approach. Dynamic stability limits can only be seen by analysing the wider region.	TSOs of the CCRs

Recommendation concerning implementation of observability area

ID	Recommendation	Justification	Responsible
Modelling and execution of (n-1) calculation			
R-6	**Monitor the implementation of** the common approach to determine and update **the observability area**.	The analysis of the incident emphasises the importance of the accuracy of operational security analysis across all timeframes. The implementation of an adequate observability area serves as an important contribution to this.	ENTSO-E

Recommendation concerning CSA and CCC in SEE

ID	Recommendation	Justification	Responsible
Coordinated Processes in South-East Europe			
R-7	The possibility of developing a more **sustainable solution for CCC and CSA for non-EU TSOs in the Balkans area and between these TSOs and neighbouring EU TSOs** should be assessed in order to increase the system security and ensure a proper level of TSOs cooperation.	Currently non-EU TSOs in the Balkans area do not belong to any CCR, despite the flows within them and within neighbouring EU TSOs having an influence on the CCC in both the Core and SEE CCRs. The capacity calculation is usually left to bilateral agreements without a proper coordination among the different borders (both non-EU and EU) and this impacts the system security of the entire SA.	TSOs and NRAs

Recommendation concerning modelling and execution of (n-1) calculation

ID	Recommendation	Justification	Responsible
Modelling and execution of (n-1) calculation			
R-8	It should be mandatory to **include** outages of any transmission elements (incl. **busbar couplers**) **in the contingency lists** in the event of a cross-border effect, if they are protected by overcurrent and over-/under-voltage protection devices. A TSO's SCADA system and the modelling of the respective system elements in the IGMs across all timeframes must allow for the simulation of such contingencies.	The inclusion of the tripping of the busbar coupler in Ernestinovo in the contingency list of HOPS would have allowed an earlier identification of the (n-1) violation. At neighbouring TSOs, operators would have been more aware of the effects of a contingency of the busbar coupler in Ernestinovo on their grid. The probability of a tripping of the busbar coupler is significantly increased when the busbar coupler is protected by an overcurrent protection. Therefore, it is recommended to include the busbar coupler in the contingency list, if it is protected by an overcurrent protection.	All TSOs

Recommendation concerning detail of data model

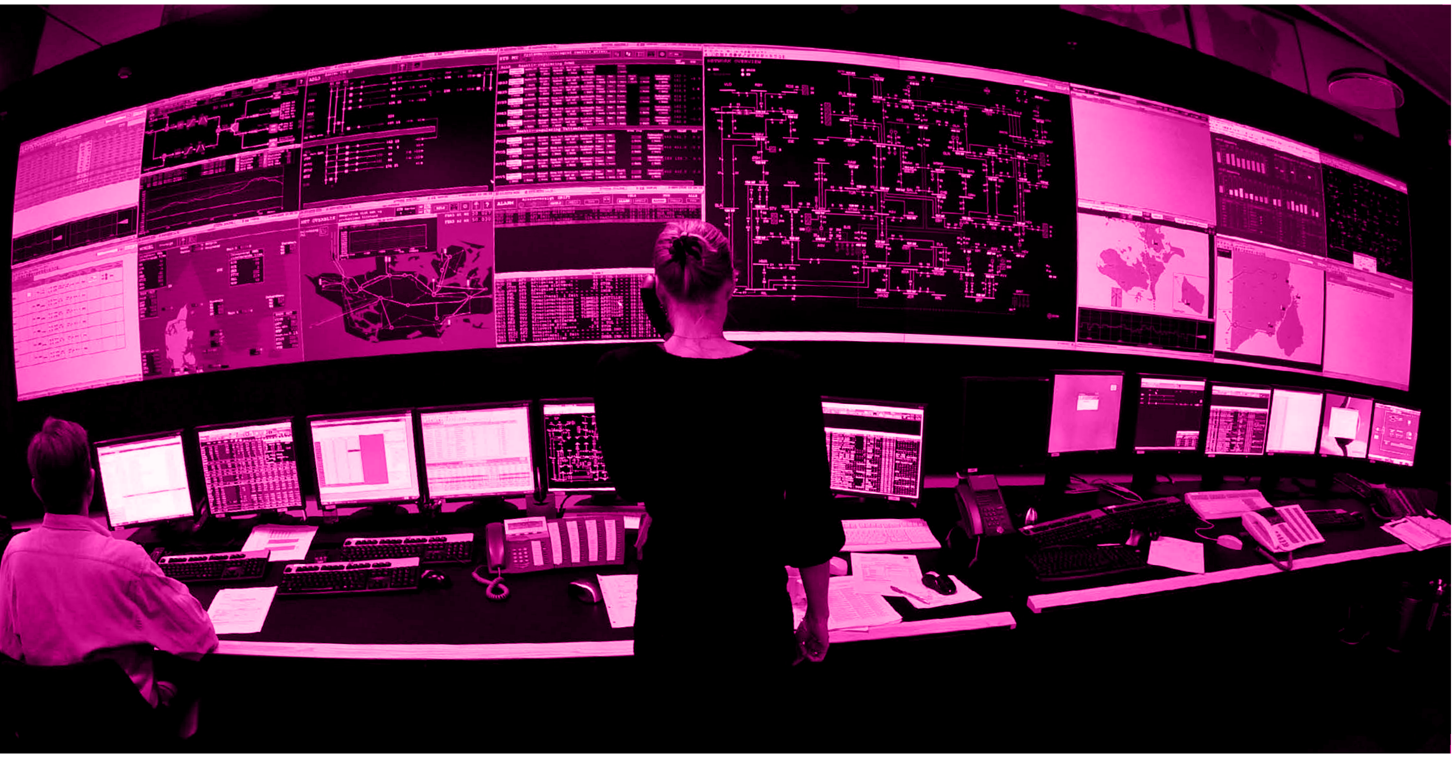
ID	Recommendation	Justification	Responsible
Modelling and execution of (n-1) calculation			
R-9	When **creating IGMs**, all TSOs shall model the grid in such a way that the power flow limits of all relevant grid elements can be assessed. This includes the **modelling of busbar couplers** (for instance as branches with low impedance) in case they are subject to relevant power flow limits (e.g. resulting from overcurrent protection) and may also include **modelling additional parts of the distribution system**. In particular, the topology of the substations shall clearly	It is required to keep the power flow limits within the operational security limits after the occurrence of a contingency from the contingency list. Modelling the transmission network in a suitable manner is a prerequisite to ensure this in the operational planning processes.	All TSOs

Recommendation concerning forecast quality

ID	Recommendation	Justification	Responsible
R-10	Assess and improve the forecast quality, particularly the IDCF quality, to **reduce** the **difference of results of IDCF and real-time calculations**.	The present process for IDCF data model creation is not standardised. A high-quality IDCF is essential for a secure system operation.	ENTSO-E

Recommendation for further legal analysis

ID	Recommendation	Justification	Responsible
R-11	Carry out a detailed analysis of the technical issues highlighted in the report to verify that the relevant TSOs comply with the SO Regulation and associated methodologies concerning the safeguarding of the operational security, and, if necessary, propose an action plan to improve the consideration of the legal requirements.	The SO Regulation and the associated methodologies lay down several legal obligations for TSOs in order to safeguard the operational security. Rules on power flow, contingency analysis, dynamic stability management, and data exchange are complexly intertwined, so it is necessary to carry out a detailed analysis to verify that the relevant TSOs comply with the SO Regulation and associated methodologies, and to propose any necessary corrective measures.	Assessment team of legal experts, composed of both regulators as well as ENTSO-E.



Recommendation for dynamic stability margin

ID	Recommendation	Justification	Responsible
R-12	For critical transmission system corridors, the **stability margin** must **be assessed in operational planning and real-time operations**. Furthermore, **operators** must be **trained** in the field of dynamic stability.	On the day of the incident the system was close to the dynamic stability limit. Usually the stability is not assessed in detail during operational planning and real-time operation. Therefore, methods for the assessment have to be developed. The calculations and measurements (PMUs) of the voltage-phase angle differences can serve as indicators for a potential system stability limit. The application of these methods shall be coordinated and used by all TSOs of a synchronous area.	Regional Group Continental Europe TSOs in coordination with relevant NRAs and ACER
R-12.1	Consider the **dynamic stability in the short-term studies**. As part of this recommendation, it could be useful to study the best practices of the Nordic and UK groups. The goal is to have a pragmatic and secure approach to obtain quick-wins, including how to incorporate potential stability constraints in the capacity calculation process		
R-12.2	Reasonably ensure that the weakest points of the network have been studied and that appropriate measures are taken (e.g. PST installations, NTC limit). To do so, the use of historical and statistical flow and temperature charts could be very useful. The objective is to transform certain risk scenarios (after analysing the split-lines) into clear instructions for the operators to avoid potential incidents of this type in the future.		

Recommendation for reduction of system inertia

ID	Recommendation	Justification	Responsible
R-13	Due to the future decrease of conventional power generation sources and a corresponding **reduction of the system inertia, compensational measures** must be identified and implemented where identified.	Considering future developments, the frequency support by system inertia is on a critical path. Therefore, biennial inertia studies need to be duly carried out in accordance with Article 39 (3) of the SO GL.	TSOs

Recommendation for non-grid code conform disconnection of generation and loads

ID	Recommendation	Justification	Responsible
R-14	For the TSOs, where a **non-conform disconnection** of generation and loads occurred during this incident, each TSO must **review the cause with generation companies and DSOs** and **derive corrective measures** to avoid the non-conform disconnection in the future. Progress of the corrective measures will be monitored by ENTSO-E and ACER.	It is to be assumed that for the case of more severe events and related higher frequency deviations, the percentage of disconnected power will be much higher and will lead to a more severe system disturbance.	TSOs to implement ENTSO-E and ACER to monitor

Recommendation for Frequency Stability Evaluation Criteria for RoCoF

ID	Recommendation	Justification	Responsible
R-15	Given that system separation events occur on rare occasions, it is reasonable to use the recorded dynamic behaviour of the system (including the implemented interruptible load schemes) when evaluating frequency stability evaluation criteria for the synchronous zone of Continental Europe and to verify the dynamic stability models accordingly.	RoCoF values of – 60 mHz/s and +300 mHz/s were measured in the north-western and south-eastern areas, respectively. These values and related transients confirm the limit value of 1 Hz/s as a pragmatic sustainable RoCoF reference for the system. System separation events can serve as a valuable input to define normative incidents to be used in the dynamic system studies.	ENTSO-E

Recommendation for frequency support and stability

ID	Recommendation	Justification	Responsible
R-16	Evaluate for future scenarios if the available fast-acting power support is sufficient, the point when a certain power transfer between power system regions exists and a system separation occurs.	If the power transfer between power system regions becomes higher, the fast-acting power reserves will have to be complemented with additional fast support beyond the classical FCR reserves. This could be either coordinated and geographically balanced special protection schemes including disconnection of contractual industrial loads and/or EPC (emergency power control, functionality of DC converters) from other synchronous areas. Otherwise, the last measure according to the defence plan in the case of underfrequency is the disconnection of demand.	ENTSO-E

Recommendation for System Defence Plans

ID	Recommendation	Justification	Responsible
R-17	CE TSOs should assess the impact of system defence plan measures between 49.8 Hz and 49 Hz, as set up by different TSOs, in order to determine any adverse cross-border impact under different emergency state scenarios. Equally, TSOs should aim to harmonise these measures so as to attain a gradual frequency response and a level playing field (similar to the automatic low frequency demand disconnection scheme).	Substantial automatic frequency-dependent system defence plan measures were triggered in France and Italy, which significantly supported the system frequency on the north-west area. These measures currently trigger first during the large frequency drops, which raises the question of whether a level playing field exists (in relation to activation criteria and compensation) in the CE SA. Equally important is the question of whether such measures when activated under different scenarios (e.g. system separation) could generate any adverse load flow patterns across different regions, further exacerbating the system conditions.	ENTSO-E

Recommendation for frequency support from embedded HVDC cables

ID	Recommendation	Justification	Responsible
R-18	The automatic control of embedded HVDC systems, which remain connected between two asynchronous areas after a system separation, should be assessed to support frequency management procedures where it is technically possible.	An automatic modification of the transmitted active power infeed of embedded HVDC systems directly after a system separation can positively assist the frequencies in both areas and in addition can help to reduce the amount of manual actions that may be necessary during such events.	ENTSO-E and TSOs

Recommendation for the operation of IGCC during system separation

ID	Recommendation	Justification	Responsible
R-19	Determine **procedures** for the imbalance netting as well as the exchange of reserve in case of a **system separation** for current and future **balancing platforms**, i.e. IGCC, PICASSO, MARI and TERRE.	If the power system is separated between two areas, any imbalance netting or exchange of reserve between both areas should be stopped. Otherwise, imbalances in the system will not be resolved and could lead to a larger disturbance of the system.	TSOs

Recommendation for data representation in EAS

ID	Recommendation	Justification	Responsible
R-20	Further **functionalities** based on the evaluation of the incident shall be implemented in the EAS system to further **improve the operator's** use of the EAS system in the event of system separation.	The incident has revealed further improvements of the EAS system, e.g. an automatic detection and alarm in case of system separation, inclusion of wide area monitoring system measurements (voltage-phase angles, automatic grid event detection, resynchronisation points, etc). In order to further improve the usage of the system, those functionalities must be identified and implemented.	TSOs & ENTSO-E

Recommendation for Region Continental Europe resynchronisation procedure

ID	Recommendation	Justification	Responsible
R-21	In addition to the currently established legal framework and policies, the communication between a multitude of TSOs can be enhanced by the development of an RG CE common **procedure** for **resynchronisation** in case of **system separation** with two or more areas (but without larger areas without voltage). The appropriateness of the requirements of SAFA Annex 5 C-19 (TSO Frequency Control Modes) should be considered within the procedure.	Overall, the communication, coordination and resynchronisation of the separated grid areas during this event were successfully implemented. Nevertheless, in the event of larger or more difficult events, the coordination and communication between TSOs could be more complex and a new RG CE common procedure should be developed to support the system resynchronisation for such events. Additionally, to freeze frequency restoration controllers due to synchronous area separation could be the right or wrong decision and needs to be considered based on the actual system conditions at the time of the event (e.g. it may not be possible to control the frequency if one area in RG CE is very large and so only one TSO has the LFC in frequency control mode).	TSOs

Recommendation for regional coordination

ID	Recommendation	Justification	Responsible
R-22	Even though the resynchronisation was successful and timely, ENTSO-E and TSOs could determine areas where the coordination of regional restoration could be strengthened if needed.	Due to the limited observability, the resynchronisation leader may face challenging situations when determining the sequence of additional connections between the synchronised regions. Relevant RCCs with larger offline geographical coverage could propose an optimal sequence of additional connections between the synchronised regions, if requested by TSOs.	ENTSO-E and TSOs

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